A passive copper shield for the split MRI system

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Introduction: The switching gradient fields in magnetic resonance imaging (MRI) systems generate eddy currents in the surrounding conducting materials. The effects produced by the eddy currents, such as Joule heating, acoustic noise, vibrations and image artefacts, degrade the performance of the MRI system. Both active and passive shielding approaches have been used to minimize these eddy current effects [1, 2]. Recent developments have been made to combine the MRI system with other imaging modalities, such as positron emission tomography (PET), into a single device. One approach to combine PET and MRI in a single device is to split the MRI scanner into two halves to provide space for the PET in the central gap [3]. It is expected that the deleterious eddy currents effects increase in these split MRI systems because of the gap in the active and passive shields of the gradient coils through which magnetic flux may escape and generate more eddy currents in the surrounding conducting materials. In this study, the change in shielding efficacy was simulated for the addition of a passive copper shield in a split MRI system.

Methodology: A split MRI system was simulated with a passive copper shield interposed between a split, actively-shielded, transverse gradient coil and the magnet cryostat, as shown in Fig 1. A range of split gradient coils were designed to ensure a 99% shielding efficiency with varying central gap size, where the shielding efficiency was defined here as the ratio between the secondary magnetic field generated by the eddy currents and the primary gradient field generated by the gradient coils. The central gap sizes were 0 cm, 12 cm and 20 cm, where the 0 cm central gap size represents a conventional MRI system. The copper shield had a 44.55 cm inner radius, 140 cm total length, 1.7×10^{-8} Ω·m electrical resistivity, and was simulated with different thicknesses: 1 mm, 2 mm and 4 mm. The stainless steel cryostat inner bore had a 45 mm inner radius, 3.18 mm thickness, 170 cm axial length and 9.6×10^{-7} Ω·m electrical resistivity. Both the copper shield and the cryostat inner bore were split in two halves with the same central gap size as the split gradient coils. The efficacy of the copper shield in terms of the eddy current reduction in the cryostat was analysed by simulating the power dissipated in the cryostat inner bore. A similar approach has been used before to study the power loss reduction in a cryostat inner bore induced by shielded z-gradient coils [4]. The eddy currents induced in the copper shield and the cryostat inner bore were simulated by the Fourier series network method [5], which were used to estimate the secondary magnetic field and power loss in these conducting surfaces.

Results and discussion: Fig 2 shows the power loss in dBm generated by the eddy currents induced in the cryostat inner bore. The 'dBm' denotes the power ratio in dB of the measured power deposition referenced to 1mW. It was simulated that the power loss in the cryostat inner bore was significantly reduced by the presence of the copper shield in all the three gap size cases. It means that the shielding efficiency in terms of minimizing the leakage magnetic field out of the gradient coils is improved. In low frequencies (within 1 kHz), more power loss in the cryostat inner bore was reduced for thicker copper shields. However, at frequencies higher than 1 kHz, all copper shields have the same shielding effect due to the smaller skin depth in copper at high frequencies. The power dissipated in the copper shield by the eddy currents was also studied in this work, as shown in fig 3. Less power was dissipated in thicker copper shield due to the decreased resistivity of the material. In fig 3 (c), more power was induced in the 20 cm gap size case, it is because of the decreased shielding efficiency of the split gradient coils caused by the increased gap size. Another eddy current effect was studied by the total secondary magnetic field along *x*-axis which was generated by the eddy currents induced in the copper shied and the cryostat inner bore, as shown in fig 4. It was simulated that the secondary magnetic field was increased in all the three cases when the copper shield was introduced, which was caused by the extra eddy currents induced in the copper shield. Fig 4 (c) shows the secondary magnetic field increases dramatically when the copper shield was introduced in a system with a 20 cm gap.

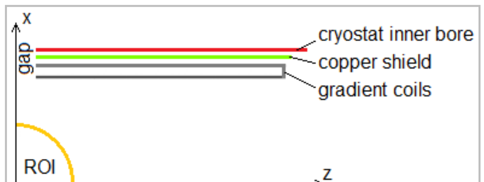

Fig 1. One quarter of the cross-section of the split whole-body MRI system

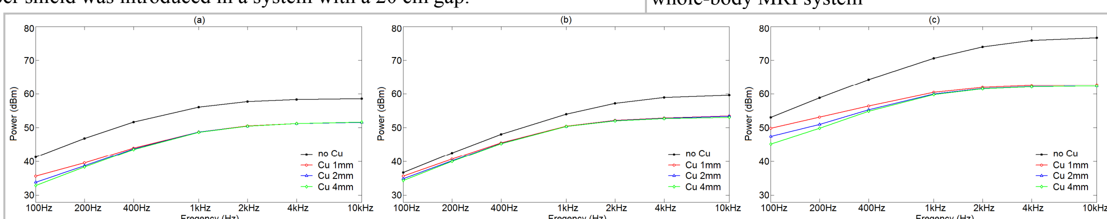

Fig 2. The power loss in dBm induced in the cryostat inner bore for various thick copper shield and gap size. Gap size (a) 0 cm, (b) 12 cm, (c) 20 cm. Label 'no Cu' refers to the configuration without copper shield. Label 'Cu 1mm' refers to the configuration with a 1 mm thick copper shield, the same as the labels of 'Cu 2mm' and 'Cu 4mm'.

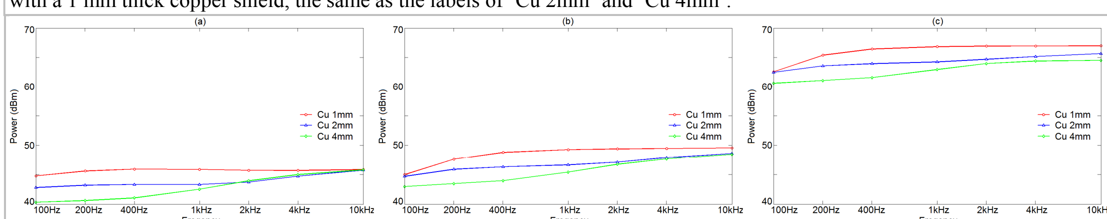

Fig 3. The power loss in dBm induced in the copper shield for various thickness and gap size. Gap size (a) 0 cm, (b) 12 cm, (c) 20 cm. The labels are the same as fig 2.

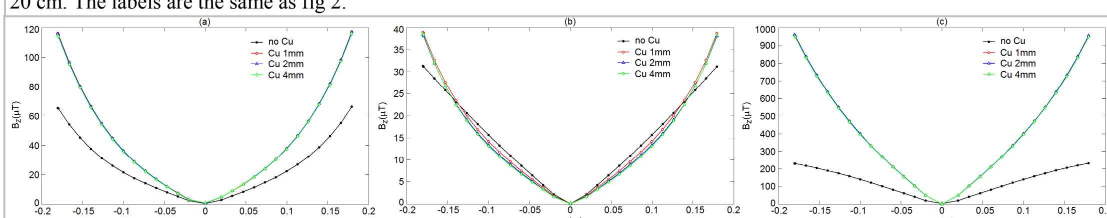

Fig 4. The absolute value of the secondary magnetic field along *x*-axis for various thick copper shield and gap size. Gap size (a) 0 cm, (b) 12 cm, (c) 20 cm. The labels are the same as fig 2.

Conclusion: The effect of introducing a passive copper shield to a split MRI system was simulated in this work. This approach appears to reduce the power loss in the cryostat inner bore, which is related to the Joule heating, mechanical vibration and acoustic noise of a MRI system. However, the power dissipated in the copper shield was increased due to eddy currents. Comparing with the complicated cryostat, the power loss in the copper shield should be much easier to be ameliorated by applying extra cooling system to decrease the temperature or doing axial cuts on the copper shield to reduce the eddy currents. Another effect of this approach is that the secondary magnetic field increased due to the extra eddy currents induced in the copper shield, especially with a large central gap size in the split MRI system.

References: [1]. Mansfield and Chapman, *Journal of Physics E*, 1986. 19(7): p. 540. [2]. Turner and Bowley, *Journal of Physics E*, 1986. 19(10): p. 876. [3]. Poole, et al., *MRM*, 2009. 62(5): p. 1106-1111. [4]. Edelstein, et al., *MRM*, 2005. 53(5): p. 1013-1017. [5]. Lopez, Poole, and Crozier, *JMR*, 2010. 207(2): p. 251-261.